Vol. XXXVIII. DECEMBER, 1897.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

No. 814.

ASPHALT AND ASPHALT PAVEMENTS.

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PRESENTED MAY 5TH, 1897.

WITH DISCUSSION.

Asphalt.—The bitumen which forms the base of asphalt is defined by Professor S. F. Peckham as "that large class of substances occurring in Nature as minerals and consisting chiefly of mixtures of compounds of carbon and hydrogen, with nitrogen, sulphur and oxygen as more rare constituents." In this paper bitumen will be considered as any natural hydro-carbon soluble in carbon bisulphide, and any substance containing hard bitumen will be called asphalt. Of the bitumen itself, the portion soluble in ether is called petrolene, and the remainder, soluble in chloroform or carbon bisulphide, asphaltene. For an asphalt suitable for paving, the bitumen should contain not more than 25% or 30% of asphaltene.

The amount of bitumen in asphalt is not so important as regards final results, but its relative quantity influences the commercial value of the asphalt in consequence of the cost of handling and refining it, and particularly in consequence of the effect it has on the number of yards of pavement that can be laid per ton of crude material.

This bitumen is of varying quality, and upon its character depends the value of the asphalt for paving purposes. The petrolene gives the cementing property to the asphalt, while the asphaltene forms the body of the material. If an asphalt contains too much petrolene, it is soft and sticky and makes a sticky pavement. If the asphaltene be in excess, the pavement will be hard and liable to crack and disintegrate. The petrolene is the solvent for the asphaltene and must be added to a hard asphalt in such quantities as will give an asphaltic cement of proper viscosity. Upon the preparation of this asphaltic cement depends the success of the completed pavement.

According to Boussingault the formula for petrolene is $C_{20}\,H_{32}$, and for asphaltene $C_{20}\,H_{32}\,O_3$; that is, the petrolene has become oxidized. Thomson deduces the following formulas: petrolene, $C_{10}\,H_8$; asphaltene, $C_{20}\,H_{16}\,O_3$. These two substances, it should be said, have not been clearly determined by chemists, whose results vary greatly.

The opinions of Dr. H. Endemann* would seem to overturn the generally accepted theories as regards the nature of asphaltene and petrolene. He adopts a different method of analysis and arrives at very different results. In speaking of the present methods in use in America, he says:

"I had to admit and do admit that the analysis as carried out by the later methods suffices to make identity or non-identity of two samples probable or highly probable. It is also adapted to watch the supply of a single mine or the refining of asphalt from the same source; but it does not admit of basing any conclusions upon the results, if we work on asphalts from different sources."

He proceeds to demonstrate by an analysis of refined Mexican and Trinidad asphalt, using the two processes, that the product which has generally been called petrolene contains only about 43% of petrolene proper, the reason being that when asphalt is treated with petroleum ether, not only the petrolene is dissolved, but also a large amount of asphaltene. By these analyses he deduces the following results:

	Petrolene.	Asphaltene.
Trinidad Lake..........	13.70 per cent.	46.28 per cent.
Trinidad Land..........	10.74 "	47.70 "
Mexican................	37.45 "	59.85 "

*See an article entitled "An Analysis of Asphalt" in the *Journal* of the Society of Chemical Industry, Vol. xv, No. 12.

and adds:

"I believe no one accustomed to the figures generally reported for these three excellent asphalts would recognize them in this shape." By a further analysis he deduces for asphaltene the formula $C_{13} H_{18} O$ or a multiple, and for petrolene $C_n H_{2n}$, adding:

"While the formula for asphaltene is verified by direct analyses, that of petrolene is deduced from a mixture, and may require verification. Petrolene also includes a series of compounds, while asphaltene appears as a single body. It differs from the substance called asphaltene by Boussingault by containing less oxygen."

He gives the following as a result of an analysis of refined Mexican asphalt by the old method and the one proposed by himself:

	Old Method.		Proposed Method.	
Petrolene	87.12	per cent.	26.51	per cent.
Asphaltene	10.19	"	70.80	"
Inorganic	0.27	"	0.27	"
Organic, not bituminous	2.42	"	2.42	"
	100.00		100.00	

He further says:

"I have been asked whether it would not be possible to recalculate the many analyses of especially crude asphalts made during the last few years to avoid the loss of so much labor. To this I have to answer that it is not possible for the reason that the higher petrolenes, when dissolved in petroleum ether, exert a greater dissolving influence upon asphaltene than the lower.

"However, as regards refined paving asphalts an approximation is possible, and may be reached by dividing the petrolene found according to old-style analysis by 3⅓. This will give us real petrolene. The difference between this figure and the original is to be added to the asphaltene."

This controversy must be left for American chemists to settle, for when doctors disagree, the layman should remain quiet and await results. It is not proposed in this paper to discuss asphalt in all its forms, but only in those that are used for pavements. The engineer must leave the patient investigation of these materials to chemists and accept their conclusions.

The principal places where asphalt is found are the Pitch Lake on the island of Trinidad; Bermudez, Venezuela; Seyssel, France; Travers, Switzerland; Ragusa, Sicily; and in California and Utah. Some deposits have also been found in Mexico, Kentucky, Texas, Montana, Colorado and Indian Territory.

Trinidad Asphalt.—At the time of the author's visit to Trinidad the asphalt was being dug from the lake and carted to the shore with mules. It was then loaded into lighters and taken to the ships anchored in the offing. Since then, however, the concessionaires have constructed a railroad from the shore to and around the lake, so that the pitch can be loaded upon the cars, drawn to the shore, out on an iron pier, and then dumped direct into the hold of the waiting ship, thus greatly reducing the expense of loading.

The material is easily dug up by negro laborers with ordinary pickaxes in chunks averaging about one-half a cubic foot each, the excavations being made of perhaps 5 or 6 ft., or of any convenient depth.

These excavations will fill up from the pressure below in about 48 hours. The surface of the lake has been compared to one formed by placing together a number of large mushrooms, the water previously spoken of standing in the depressions where the mushrooms come together. It has been thought by geologists that this appearance was caused by the material being forced up in a liquid form through a large number of orifices. These different streams, coming together at the top, form a surface, which, when hardened, presents the appearance described.

The asphalt is brought to this country generally in its crude state, and is refined at various points where most convenient for distribution. This refining process consists of heating the material in large iron retorts to a temperature of about 400° Fahr. for five or six days. This serves to evaporate all the water, and drives off all the volatile oils. The solid foreign matter is allowed to settle to the bottom, and the remainder is drawn off into barrels for shipment. The sediment is then taken out, and is used for sidewalks or similar purposes. Three tons of the crude material makes about 2 tons of the refined.

Another process of refining or drying asphalt has been used more recently. The apparatus consists of an iron tank large enough to contain about 30 tons of the material. In this tank is a continuous pipe arranged in gangs, something similar to a steam radiator, having a steam pipe to take the condensed water back to the boiler. Another set of pipes, called the live-steam pipes, has a direct boiler connection and a number of jets inserted in it at the bottom, so that the material in the tank can be kept in constant agitation by the injection

of hot steam through these jets, thus ensuring a complete and even mixture, as well as more rapid evaporation. After the tank is filled with asphalt, steam is applied at a pressure sufficient to produce a heat of about 300° Fahr. The application of this heat for fifteen or sixteen hours is sufficient in most cases to evaporate all the water from the asphalt, when it is drawn off into barrels for shipment. If the material is to be used near the refining plant, the flux is added before the product is drawn off and the asphaltic cement made on the spot. This method is generally called the drying process, and is economical, both in time and material, as it only requires sixteen hours against ninety by the old, and there is no wastage of material. It is held that as so large an amount of extraneous matter must be added to make the pavement, it is a waste of material to lose the amount of sediment which is very similar to what is afterwards added, and under the old plan was often a total loss. This system has been in operation about two years.

An analysis of the refined lake product gave the following result: bitumen, 55.6%; foreign matter, 44.4%; petrolene, 70.12%; asphaltene, 29.78%; specific gravity, 1.38.

California Asphalt.—California produces nearly all the United States asphalt used for paving purposes. While it can be found in this state in nearly all its stages of development, but three of these are adapted to pavements, namely, the maltha, hard asphalt and bituminous rock.

Maltha is a liquid asphalt used principally as a flux for the harder material. It contains a large percentage of bitumen, of which nearly all is petrolene; this determines its value as a flux. On account of the inconvenience of shipping it in its natural condition, the asphaltic cement is made near the mines, which are in Santa Barbara County near the city of the same name. The sand and vast beds of underlying shale in this vicinity are saturated with the material, but at present the maltha is obtained from the sand. An upper surface of about 1 ft. of soil is washed off into the ocean and the bed of sand left full and clean. This sand is then gathered up and the maltha extracted by a patent mechanical process. This bed probably extends for several miles under the sea, as the water for a long distance up and down the coast is covered with an oily film showing that this same material must be forced up from the bottom of the ocean. The composition

of this material when ready for use is 98.26% bitumen and 1.74% mineral matter; the petrolene amounts to 92.5 per cent. The specific gravity is 1.05.

Some 25 miles east of this deposit is located the principal deposit of the hard asphalt, which extends over an area of several hundred acres. This material is quite hard, presenting an appearance somewhat similar to refined Trinidad. When refined it is treated in practically the same manner as that before described, but the paving cement is often made by mixing the crude material and the maltha at a low temperature for only a few hours, the proportions of the mixture depending upon the consistency of the cement required. The composition of the natural product is: bitumen, 59.15%; organic matter, 1.10%; mineral matter, 39.75%; petrolene, 42.50%; specific gravity, 1.25.

Another deposit of hard asphalt has been found in Kern County of probably the same origin, but containing a larger percentage of bitumen. It is treated, both in refining and fluxing, in the same manner as that from the Santa Barbara mines. The refined product contains: bitumen, 93.27%; mineral matter, 5.77%; organic matter, 0.54%; moisture, 0.42%; petrolene, 71.27%; asphaltene, 28.73 per cent.

In Santa Cruz, San Luis Obispo and Monterey Counties are found deposits of asphalt of an entirely different nature, and pavements laid with their product must not be confounded with the others. It consists of sand thoroughly mixed with an asphalt of such a nature as to make a good pavement in a natural state. The sand is of all grades of fineness, sometimes largely mixed with clay, and often so hard as to be almost a sandstone. Pavements of this material have been quite extensively laid in California cities, the method being simply to heat the crude product so that it can be rolled to a hard smooth surface on the street, in some cases without any prepared foundation. It is not strange that the results of such operations should often prove failures, as no special care seems to have been taken to select the best of the materials at hand. These failures have sometimes been charged improperly to the other California asphalts.

Bermudez Asphalt.—The deposit of Bermudez asphalt is situated in the state of the same name in Venezuela. It is across the Gulf of Paria from the Island of Trinidad, and some people think the two

deposits are connected subterraneously. The lake is about 5 miles from the shipping point, which itself is 25 miles up a river from the Gulf. It includes an area of some 1 200 or 1 500 acres, covered generally with quite a heavy growth of grass and bushes. Through the lake runs a so-called stream of liquid asphalt, varying in width from 100 to 400 ft. With the exception of this stream, a person can easily walk over the entire surface of the lake, but upon the stream itself it is not safe to venture after the sun is two or three hours high. A portable railroad is built out into the lake, upon which light hand-cars are run. After being loaded, the cars are pushed to the shore, where they are unloaded into other cars, and the material then hauled to the shipping point over a permanent steam railroad. These cars are provided with boxes each containing about a ton of the crude material, and when delivered alongside the vessel at the wharf, the boxes are hoisted from the cars and lowered into the hold of the vessel and there dumped.

The first pavement of Bermudez asphalt was laid in Detroit in 1892. When refined, the asphalt is composed of: bitumen, 97.22%; mineral matter, 1.50%; organic matter, 1.28%; petrolene, 77.90%; asphaltene, 22.10%; specific gravity, 1.08.

Utah Asphalt.—The deposits in Utah are situated in Utah County, and are found in a vein of limestone about 8 ft. in thickness, only one-fourth of which contains sufficient bitumen to make it profitable for use, the amount being about 30 per cent. In eastern Utah is another deposit called gum asphalt, which is claimed to be pure bitumen. An analysis shows: carbon, 81%; hydrogen, 10%; nitrogen, 3%; and oxygen, 6 per cent.

In preparing a mixture for street work the gum asphalt is melted and fluxed with a small amount of residuum. It is then mixed in the proper proportions with hot sand and the bituminous limestone. This mixing is done in cylinders surrounded with steam jackets, in which steam is kept at a temperature of 600° Fahr. during the mixing, which continues a few minutes, when the mass is dumped into carts and taken to the street. Pavements of this material have been laid in Salt Lake City, Minneapolis, and Marion, O.

Kentucky Asphalt.—The Kentucky deposits are found in sandstone, and should be classed with the rock asphalts. The output is not large, and very little information could be obtained concerning it. Some years ago two pieces of pavement were laid with this material in Brooklyn,

and while some of it is in existence now, so little care was taken as to time and manner of laying that the experiment has been of little value.

Indian Territory Asphalt.—The asphalt deposits of Indian Territory are located in the southwestern part of the territory in the Arbuckle Mountains, near the Washita River. They extend over an area of several square miles. The asphalt is found in sand and also bituminous rock. The former contains $16\frac{7}{8}\%$ and the latter 21% of bitumen. The sand asphalt is used in its natural state in pavements. It is heated in a special apparatus and laid in much the same way as the European rock asphalts, but to the rock asphalt 50% of sand asphalt is added before heating, when it is laid as before. Nearly all the work in the development of this deposit has been done during the past eighteen months, the charter for the company from which the present operators leased it having been granted in 1895; consequently very little pavement has been laid with this material, that little being principally in the repairs of other pavements. Where used, it has so far given good satisfaction, though from its amount of bitumen it might be expected to make a pavement that would be too soft.

By a process of refining, a bitumen of about the consistency of maltha is produced from the sand asphalt. It is first separated from the sand by being boiled in water. The asphalt, having a smaller specific gravity than water, rises to the surface, when it is skimmed off and still further refined as required.

European Asphalt.—The European asphalts, although somewhat scattered, are found under about the same conditions. They exist in strata of varying depths, from 6 to 23 ft. in thickness, separated from each other by impermeable beds of limestone.

It is supposed that at an early period bitumen must have been vaporized by extreme heat, that the hydro-carbon in a state of vapor was forced through this limestone while soft, much as subterranean water follows layers of gravel confined by beds of clay or stone, and that fissures in the overlaying rock have permitted the vapor to pass to the other soft strata above. The rock absorbed this vapor to a greater or less extent, and the geological changes occurring in the succeeding years produced the rock asphalt as it is found to-day. To make a good pavement this rock should contain from 9.5% to 10% of

bitumen, according to conditions. If one deposit contains too much, it can be mixed with another compound containing less. According to the solvents used, the products of the same mine will produce different results, and that may account for the results given here from three different sources. The bitumen and carbonate of lime form so very large a percentage of the whole that the other ingredients are not considered.

Ragusa.		Seyssel.		Val de Travers.	
Bit.	Carb. of lime.	Bit.	Carb. of lime.	Bit.	Carb. of lime.
9.72	88.75	8.15	91.70	12.00	....
8.92	88.21	9.10	90.35	7.20	....
....	....	7.00	....	10.25	88.40

Pavements.—In 1854 a pavement of rock asphalt was laid on the Rue Bergère, Paris, as an experiment, with such success that four years later another trial was made on Rue St. Honoré, from which time may date the beginning of asphalt pavements. In London the first pavement similar to this was laid in 1869, and in Berlin in 1873.

Asphalt as generally laid in this country is a bituminous concrete, the sand acting as the body of the mixture, the asphalt simply cementing the particles of sand together.

The success of the European pavements led investigators of this country to make experiments in their own behalf, and from 1870 to 1873 quite a large area of pavement was laid with coal-tar instead of asphalt as a binding material. These pavements failed, as the coal-tar was apt to crack in the winter and be soft and sticky in the summer; or, in other words, a pavement made of coal-tar that would not be soft in hot weather would crack and crumble when the weather became cold. Chemically there is not much difference between coal-tar and asphalt; in fact, the author was once told by an eminent chemist that he knew of no chemical test by which the presence of coal-tar could be detected in asphalt. If it exists in any amount, however, it can readily be discovered by its odor.

The failure of these pavements led to further investigation on the part of interested people, and in 1870 a bituminous pavement* was laid in Newark, N. J., around the City Hall, followed in 1871 by one in New York, near the Battery, with Trinidad asphalt as the cementing material.

* There is some doubt as to the composition of the Newark pavement. The records do not say whether it was asphalt or a coal-tar mixture.

About the same time a similar pavement was laid in Philadelphia, and a few years later others in New York. These experiments were so successful that they attracted the attention of the authorities of Washington, and in 1876 a commission appointed under the authority of Congress reported in favor of paving Pennsylvania Avenue with asphalt, using the European bituminous rock on one portion and Trinidad asphalt for the remainder. From the completion of that work dates the entire success of asphalt pavements in the United States, and although a great amount of careful study and further investigation was necessary, the industry has been continually on the increase since that time.

Some eight or nine years ago, in making his annual report to the city council of Omaha, the author had occasion to say that stone and asphalt were the only real paving materials. The experience of the years since then has only made stronger that belief. For a street subjected to heavy traffic there can be no question that granite properly laid makes the best and most economical pavement, but for a moderate traffic, on reasonable grades, asphalt will give the most general satisfaction. It is smooth, almost noiseless, and can be kept clean. As a sanitary pavement, it is without a rival. It is said to be expensive, and it is, to a certain degree, but very few who use it will doubt the value received. The question of cost and durability will be discussed more in detail later. Some asphalt pavements have failed, but that is not surprising when it is considered how new the industry is, how rapidly it developed, and that all facts about its construction had to be established by pavements actually in use.

The question of how steep a grade on which it is safe to lay asphalt has received a great deal of study. Originally grades of even 4% were considered prohibitory, but as more work was done, this was seen to be too conservative a view. Asphalt is now in use upon grades in different cities, as follows: New York City, 6%; Omaha, Neb., 7% to 8%; Brooklyn, N. Y., 4½%; Syracuse, N. Y., 7 per cent.

The objection to steep grades is, of course, the liability of horses to slip. Contrary to the general belief, asphalt itself is not slippery. It is smooth, and any soft substance upon a smooth surface makes it slippery, but on steep grades foreign matter is less liable to collect than on light ones. The remedy, then, is to keep the pavement clean. It is a fact known by all teamsters that it is harder for a horse

to travel on a smooth pavement when it first begins to rain than after a heavy shower when the surface has been washed clean. In view of the experience of the past few years and the fact that all pavements are kept much cleaner than in former times, the conclusion is reached that grades of less than 5% need not be questioned when considering the advisability of laying a smooth pavement, and in extreme cases those as high as 6% are permissible.

The question of crown or convexity is pertinent here. Streets are paved for use, not for looks, and the cross-section that accommodates travel the best and will carry all water falling upon it to the gutters is the one that should be adopted. Some engineers have a formula for this, based upon the grade of the street and width of roadway. Theoretically this is correct, but in practice it is better to establish a minimum crown and vary from it only when it is absolutely necessary to prevent water from standing on the surface. For a roadway 30 or 34 ft. in width, the following cross-section will give satisfaction at minimum grades: Depth of gutter 5 ins., center of street 1 in. below level of curbs, the cross-section of the street being an arc of a circle. This gives the center half of the roadway a fall to the sides of 1 in. in 7½ or 8½ ft. as the case may be. This is practically level as far as travel is concerned, and for drainage purposes is about 1%, which is ample. On an asphalt street with level curbs the gutters need never be more than 6 ins. deep unless the width be extreme, and the crown of the pavement preferably not higher than the curbs, so that for widths of 50 or 60 ft. between curbs, the crown should not be more than 6 ins.

It often happens that in repaving old streets, one curb is found at a considerably higher elevation than the other. The practice then is to make the gutter on the high side of maximum depth, and that on the lower side of the minimum, thereby reducing the difference in the elevation as much as possible. If the elevation of the pavement at the quarter instead of the center be made the highest part of the roadway, the most acceptable cross-section is obtained. Some engineers in such cases advocate laying the pavement with a plane surface from gutter to gutter. By this method the side slope is minimized, but the water is all thrown into one gutter, and it is almost impossible to have work carried out so perfectly that settlements will not show in pavements so laid, holding water after every rain.

Character of Asphalt.—To make a first-class pavement the asphalt should be a good material, properly mixed and well laid upon a good foundation. Whether an asphalt will or will not make a good pavement can only be told by trying. A chemist can analyze an asphalt, tell what are its component parts, and give his idea as to what it ought to do, but the author doubts if any one would be willing to give a definite opinion as to its action in a pavement simply from a laboratory analysis. Stevenson Towle, M. Am. Soc. C. E., in speaking of the partial failure of the Eighth Avenue pavement in New York City, said:*

"This asphalt was submitted to and approved by experts and chemists before the contract was entered into. Soon after the pavement was laid and before its completion (it has never been accepted), it showed unmistakable evidences of disintegration. This failure was exceptional and the experts and chemists who had approved of the asphalt could not account for it. My own belief was that the asphalt was inferior or lacking in some essential property unknown to chemists."

Personally the author would hesitate before giving a final judgment on a pavement that had not passed through at least two winters. An analysis of the refined asphalt is required to ascertain the quantity and quality of the bitumen contained. Then, by former experience with other similar asphalts, and many experiments, the quantity of flux is determined, taking into consideration the climate and amount of traffic.

In this connection, Trinidad asphalt is generally taken as a standard, not because it is the best, but because it is known that it will make a good pavement. Any refined asphalt that contains from at least 50% to 60% of bitumen which is composed of approximately 75% petrolene and 25% asphaltene, is deserving of careful investigation and experiment.

Foundation.—The foundation is the important part of an asphalt pavement. The surface coat is only the carpet; the base must be the floor that sustains the load. No matter how good the top may be, a failure in the base means immediate failure in the pavement. Probably the best foundation and that most generally in use is made of hydraulic cement concrete. Its thickness varies with the traffic, but should never be less than 6 ins. Some seven or eight years ago, the

* See his Report to the Commissioner of Public Works of New York City, January 5th, 1895.

asphalt companies, wishing to reduce the cost of their pavements wherever practicable, experimented with a broken stone base. This stone was of the ordinary size for concrete, and, after being spread upon the prepared roadbed, was thoroughly compacted with a steam roller. Upon the broken stone was then sprinkled hot coal-tar, in quantity about 1 gall. per yard, followed by the binder course. This considerably reduced the cost of the work, but as the solidity of the pavement depended directly upon the ground beneath, its use was soon discontinued. In repaving streets, however, it is often well and desirable to retain the old material as a base. This has been very generally done, and with good results, on granite or other stone streets. A few cases where asphalt was laid over old Nicholson pavements resulted disastrously, as might have been expected. One objection to using the old stone base is that the cross-section of the street often needs to be remodeled, involving the relaying of a large amount of the stone. This requires great care to avoid future settlements. On cobble streets chuck holes and other irregularities often exist, too large to be filled economically with binder. In such cases the street can be brought to the proper cross-section with broken stone thoroughly rolled, the old cobble still being the real foundation.

Asphaltic Cement.—The first step in the actual mixing is the preparation of the asphaltic cement. A portion of refined asphalt is carefully weighed and deposited in an iron tank and melted. After it has attained a temperature of about 300° Fahr., the flux is added. If this be petroleum residuum, it is added in the proportion of from 16 to 20 lbs. for each 100 lbs. of asphalt, according to the consistency desired. The temperature is then maintained for about ten hours, the whole mass being kept constantly in agitation by means of an air blast to ensure a thorough mixing. The quantity of the oil will vary a little according to its quality, as well as that of the asphalt itself.

An ingenious machine has been invented for testing mechanically the asphaltic cement. This apparatus consists of an arm some 17 ins. long, supported at one end and provided at the other end with a cambric needle above which is placed a weight of 100 grams. The needle end is connected by a rod and cord with a large hand that moves around a dial divided into 360°. By a spring attachment the needle is brought into contact with the asphaltic cement for any desired time, and the amount of penetration marked in degrees on the dial.

For comparative tests it is of course important that all samples be used at the same temperature. This can most easily be accomplished by placing the cement in water when ready for the test and keeping it at the required temperature, generally from 75° to 80° Fahr. The author knows of no place where this machine is extensively used except in Washington. The report of the Engineer Commissioner for the year ending June 30th, 1895, gives the average penetration of the product of three companies at 77° Fahr. as 69, 73 and 85. In the following year the average of the cement furnished by one of the above companies was 75.

The residuum oil should have a specific gravity of about 20° Beaumé, a flash point of 300° Fahr., and should distil not more than 9% or 10% in ten hours at a temperature of 400° Fahr.

If maltha or some other flux be used, it should be treated practically as above, modified according to the properties of the particular material.

Wearing Surface.—Asphalt pavement was first laid in two layers, a cushion coat of ½ in., and a wearing surface 2 ins. in thickness. After some experience it was seen that the upper surface sometimes slipped on the lower, or the whole slipped on the concrete, thus forming a wavy and uneven surface. To counteract this, there was laid instead of the cushion coat, the so-called binder. This consisted of clean broken stone, cemented together with coal-tar, but later, on account of the variableness of the tar, asphaltic cement was substituted as a cementing material. The thickness of this binder is 1 or 1½ ins. As its object is simply to connect the wearing surface with the concrete, there appears to be no good reason for making it more than 1 in. Where binder is used, the wearing surface is 1½ or 2 ins. thick according to the traffic, the general practice being where the binder is 1 in. to make the wearing surface 2 ins., so as to have the pavement in no case less than 3 ins. thick.

The stone for the binder should be thoroughly clean, and vary in size from ½ in. in its smallest to 1 in. in its largest dimensions. It should be heated to a temperature of about 300° Fahr., the asphaltic cement added in the proportion of about 20 galls. of cement to a cubic yard of stone and the whole mass mixed till each piece of stone is completely coated. It is then carted to the street and spread upon the concrete so as to give the required depth when rolled. It is neither

intended nor desired to fill all the voids in the stone, and care must be exercised to use no more cement than is necessary to bind the stone together. Should there be an excess, it will rise in warm weather and soften the wearing surface, and cause a failure. Such a case as this came under the author's observation, and an analysis of the asphalt showed an excess of 50% of bitumen. The mixture for the wearing surface consists of sand, asphaltic cement and pulverized limestone. The exact proportions vary according to conditions, but in the vicinity of New York are approximately: sand, 710 lbs.; asphaltic cement, 110 lbs.; pulverized limestone, 60 lbs. These proportions will vary according to the character of the sand and amount of bitumen in the asphaltic cement, but they should produce from 9% to 11.5% of bitumen in the finished pavement.

In this mixture it is very necessary that all voids should be filled, and the amount of stone dust depends upon the coarseness of the sand. The use of the limestone dust as a filler has a tendency to make the surface hard and slippery. At first it was thought that the carbonate of lime had a chemical effect on the bitumen, but that idea is about given up, and the author believes that if there were used in its place an impalpable powder made of the silicious gravel found on Long Island, the pavements would be improved.

The sand is heated in a special apparatus to a temperature of about 400° Fahr. and elevated to the mixing platform. It is necessary that this temperature should be uniform, as an extreme heat in even a few hundred pounds might burn and destroy quite a quantity of asphaltic cement, and defects would soon develop in the pavement. While the wearing surface is being laid upon the streets, several tanks are kept full of the cement at a temperature of about 300° Fahr. The proportions having been determined, the sand, asphaltic cement and stone dust are thoroughly mixed in a pug mill for 1½ minutes, when the mixture is dumped into carts below. It should be delivered on the street at a temperature of from 250° to 275° Fahr., and experience has shown that when covered with canvas it will not lose more than 10° or 15° of heat for ordinary distances and temperatures. After being dumped on the binder, it is raked smooth and even, so as to give the required thickness after having received a compression of 40 per cent. This depth can be regulated by a good foreman with experienced rakers. The first compression should be applied with iron

rollers worked by hand. Hydraulic cement is then lightly scattered over the surface, when it should be rolled with a steam roller of 4 or 5 tons, followed in a short time by a third, weighing from 250 to 300 lbs. per inch of width. The object of the different rollers is to apply the weight gradually so as to have the whole compression vertical, rather than with a push, which might occur if too heavy a weight were applied before the material had received a partial compression, thus giving a wavy surface. The rolling should continue as long as any compression takes place, and approximately about five hours for each 1 000 yds. of completed pavement.

Too much attention cannot be given to the rolling, for upon this depends the success of the whole work. Unless thoroughly compressed, the material will have very little cohesive strength. The necessity of this was once impressed upon the author when a street was paved late in the season; and soon after its completion, the mercury fell considerably below the freezing point. This street was one of some thirty contracts that had been completed by the same contractor with the same material, all of which had given perfect satisfaction. In a few days the surface of the pavement began to pick up under travel and the contractor voluntarily relaid a portion of it. For a time it looked as if the entire block must be taken up, but the weather suddenly grew warmer, softening the material so that it would compress under travel, and in a few days the street was perfectly smooth and has remained so ever since. Had the weather remained mild for a few weeks after the work was completed, no trouble would have ensued. The rolling should be begun as soon as the material is leveled off, and continued to completion. Whenever the width will allow it, the rollers should be worked across the street, and on lesser widths diagonally from side to side so as to remove any slight irregularities of surface that might be produced by a continuous rolling in one direction. It is always difficult to get perfect compression along the curb. Consequently it is customary to paint the gutter for a width of about 1 ft. with asphaltic cement, so as to fill completely any pores that might be left open by lack of compression. This cement should be applied before the pavement has become cool, and well ironed with irons specially made and heated for the purpose.

Rock Asphalt.—Rock asphalt is taken from the mines and shipped to this country in its natural state. After being mixed in the propor-

tions determined upon, it is first crushed with rollers and then reduced to a fine powder by being passed through disintegrators, after which it is sifted through sieves to separate any lumps that might otherwise get into the pavement. This powder is then heated in a cylinder, which is kept constantly in motion to allow the air to circulate freely among the particles, and kept for about two hours at a temperature of 300° or 325° Fahr. The material is then carried in carts to the street and spread upon the prepared base to a depth that will give the required thickness when thoroughly compacted. A light roller is then run over the surface to give the initial compression, when workmen, each with a round iron rammer 6 or 7 ins. in diameter, carefully go over the portion of the street covered, all striking blows in unison on the asphalt until it is well compacted. A thin coating of hydraulic cement is spread over the surface when it is ready for the final rolling, which is done by steam and preferably with an arrangement inside the roller for keeping it hot. About twelve hours after the rolling is completed and the material has become cold, the street can be thrown open to travel, which continually adds to the compression already given.

Asphalt Block.—A form of asphalt pavement different from those just described is that composed of asphalt blocks. Pavement of this kind was first laid in San Francisco in 1869. The results were not good, but the promoters were sufficiently encouraged to continue the experiment with improved appliances until its success was assured. The blocks are generally 4 x 5 x 12 ins., but are sometimes made but 4 ins. deep where the travel is light or the foundation particularly good. They are made by mixing broken stone with asphaltic cement and subjecting the whole to a heavy pressure. Limestone has been used; trap rock is preferable, where it can be obtained, as it stands the action of the weather and traffic much better. The stone is crushed to a proper size, and after being screened is heated to a temperature of from 300° to 350° Fahr., when the asphaltic cement and a little pulverized limestone are added and the whole thoroughly mixed. The mixture is then placed in molds and a pressure of 3 000 lbs. per square inch applied until the mass is thoroughly compacted, when it is at once cooled under water and is ready for use. The proportions generally used are 77% broken stone, 13% asphaltic cement, and 10% pulverized limestone, the amount of the last varying with the size of the stone.

It is claimed by the advocates of this pavement that the blocks, being made separately, each one receiving a regular and uniform pressure, will give better results on the street than sheet asphalt. They also claim that, on account of the size of the blocks, a concrete base is not necessary, but one made of broken stone or gravel thoroughly compacted with a steam roller is sufficient, or if concrete be used the depth of the concrete can be reduced. When the foundation is prepared, the blocks are laid upon it practically as stone blocks are, care being taken to make close and straight joints across the street. This form of pavement has been laid in many eastern cities, but in and around New York does not seem to be able to compete successfully with sheet asphalt.

Cost and Maintenance.—When it is considered under what conditions and for what length of time asphalt pavements have been laid, it is not strange that reliable data as to first cost, as well as to repairs, are not at hand. Asphalt has almost always been laid with a guaranty to keep it in good repair for a period varying from five to fifteen years. The price bid has, of course, included the cost of maintenance for the guaranteed time. Throughout the West, when this pavement was first laid, it cost for years $2.95 per square yard on 6 ins. of concrete. The introduction of new asphalts, together with competition, has somewhat reduced this price, so that contracts have been made in Omaha for asphalt pavement on a 4½-in. concrete base for $2.07 per square yard, with a five-year guaranty, and in St. Paul for $2.53 and in Minneapolis for $2.43 per square yard, both of these being on 6 ins. of concrete, with a ten-year guaranty. Brooklyn has let several contracts for $1.58 per square yard on a 6-in. concrete base, with a five-year guaranty, while the Fifth Avenue pavement in New York will cost $4.60, with a guaranty period of fifteen years. Taking all conditions into consideration, these last two prices are probably as low as any paid in this country.

Different cities have different methods of making their repairs. When the guaranty periods began to expire in Omaha, in 1888 and 1889, the Barber Asphalt Paving Company entered into contract with the city to keep all their pavements in good condition for a further period of ten years for 8 cents per yard per year, making the entire cost for fifteen years $3.75. Since then, however, contracts have been entered into for a specified price per yard of material actually laid.

In Buffalo the latter method is adopted, the contractor agreeing to keep each patch in repair for a term of years. This necessitates the exact location of each patch as it is made, and in a few years the patches overlap each other, involving a large amount of work in keeping up the record.

In Washington it has been the practice to pay a specified price per cubic yard for all material used. This plan requires inspectors thoroughly conversant with their business, so that defects in material or workmanship can be readily detected.

In Buffalo, where the cost of repairs has been kept with a great deal of care, the expense has been as follows:

Years maintained.	Cost per yard per year.	Years maintained.	Cost per yard per year.
1	$0.017	7	0.0778
2	0.0305	8	0.028
3	0.038	9	0.0122
4	0.0917	10	0.025
5	0.0678	11	0.0353
6	0.0463		

The average for the above is $0.055 per square yard per year.

In Washington the resurfacing and repairs from 1879 to 1895 cost $0.077 per yard per year. During this time 676 390 sq. yds. were entirely relaid, at an average cost of $1.51 per yard. Deducting this cost from the above, the expense of actual repairs was $0.023 per yard per year. During the last two years a device has been used which has considerably decreased the actual cost of repairing asphalt. This consists of an apparatus by which a concentrated gasoline flame is thrown upon the pavement, heating it to such a degree that all the dead and inert material can be easily scraped off and the surface roughened with toothed hoes, so that the new material can be laid and compressed to give a good bond with that already on the street. By means of this machine, repairs can be made much more rapidly and neatly.

The question of repairs and how they should be made is one of great importance. It seems to the author that the method which will give the best satisfaction is to award a contract to responsible parties to keep a certain number of streets, or all in any city if the yardage be not too great, in repair for a term of five years for a specified price

per yard per year, including all streets of which the guaranty expires during the contract period. Provision should be made, of course, to reserve enough money till final payment to ensure the carrying out of the contract. By this plan it would be for the contractor's interest to keep the streets in good condition at all times, as that old proverb, "a stitch in time saves nine," can never be applied with more force than to the repairs of an asphalt pavement.

The life of the pavement varies much with conditions. Some require entire resurfacing inside of the first five years, others are reported to have lasted ten or twelve years with merely nominal repairs. In the light of present experience it would seem that asphalt on a street of ordinary traffic under normal conditions ought to last from twelve to fifteen years before requiring relaying, and should not cost more than 6 cents per yard per year for maintenance after a five-year guaranty period.

This industry, which was just being thought of in 1870, and was still in its infancy in 1880, has now assumed vast proportions. On January 1st, 1897, there was laid in this country, as nearly as could be ascertained, 27 468 915 sq. yds. of asphalt pavement, divided as follows: Trinidad asphalt, 21 527 415 sq. yds.; Bermudez asphalt, 697 500 sq. yds.; Alcatraz (California) asphalt, 916 000 sq. yds.; Standard (California) asphalt, 200 000 sq. yds.; foreign rock asphalt, 603 000 sq. yds.; Utah rock asphalt, 293 000 sq. yds.; other asphalt in the Pacific Coast States (estimated), 1 032 000 sq. yds.; asphalt block, 2 200 000 sq. yds.

Of this amount Buffalo contains more than any other American city, having at the present time 3 663 402 sq. yds. Washington, D. C., comes next with 2 554 262 sq. yds. on June 30th, 1896; this amount includes 477 416 sq. yds. of coal-tar and concrete pavement not considered in the above grand total, but excludes 170 229 sq. yds. laid in the suburbs.

Asphalt in Europe.—The principal cities in Europe having asphalt pavements are London, Paris, Berlin and Vienna. These are all laid with the rock asphalts heretofore spoken of, being called in France *asphalte comprimé*, and in Germany *Stampf-Asphaltum.*

The amounts in these cities are as follows: London proper, 208 000 sq. yds.; Paris, 403 000 sq. yds.; Berlin, 1 600 000 sq. yds.; Vienna, 93 000 sq. yds.

The original cost per square yard on a concrete base 6 to 8 ins. thick was \$3.25 in London, \$3.60 in Paris, \$2.77 in Berlin, and \$3 in Vienna.

The cost of repairs per square yard per annum was 6 to 44 cents in London, 47½ cents in Paris, and 10 cents in Berlin, for a period of fifteen years after the guaranty expired. On railroad streets 15 cents for space between tracks and for a distance of 27½ ins. (70 cms.) outside.

In considering the cost of maintenance of European asphalt pavements, the large amount of traffic they sustain must be taken into account. A report of the Chief Engineer of Paris gives this traffic as follows, the figures being the number of vehicles passing in twenty-four hours:

PARIS.

Rue de Rivoli	42 035	Rue Auber	14 082
Rue Croix des Petits Champs.	20 480	Avenue de la Grande Armée.	8 149
Rue St. Honoré	19 672		

LONDON.

King William Street	26 793	Holborn Viaduct	12 158
Gracechurch Street	15 585	Newgate Street	13 128
Queen Victoria Street	16 531	Moorgate Street	11 398
Cheapside	15 206	Cornhill	9 572
Aldgate	14 200		

DISCUSSION.

Mr. North. EDWARD P. NORTH, M. Am. Soc. C. E.—It seems very desirable that the possibilities which are presented by an admixture of the Kentucky bituminous sandstone with the ordinary rock asphalts of Europe should be more thoroughly investigated than they have been. On Sixty-fourth Street, in New York City, for 100 ft. west of Madison Avenue, the pavement, which was laid in 1891, is a mixture of 60% Sicilian rock asphalt and 40% Kentucky bituminous sandstone. The same mixture was laid at substantially the same time on Sixteenth Street, directly in front of the main building of the Willard Parker Hospital for a distance of about 100 ft. Both these pieces have worn satisfactorily. They were laid as a powder and compressed as if they had been pure rock asphalt.

Some of the European asphalts, like the Limmer and Vorwohle, and some of the material mined by the Seyssel company, contain so little bitumen that it is impossible to make a compressed asphalt pavement with them, although by the addition of more bitumen they make a very good mastic.

The Kentucky bituminous sandstone, which seems too friable to withstand heavy traffic, and this applies to all mixtures of sand and bitumen known to the speaker, has in the two cases mentioned, and also in other cases in western cities, supplied the missing bitumen without injuring the wearing properties of the rock asphalt when compressed. It seems possible that the Kentucky rock asphalt might also replace the sand and some of the bitumen composing the sheet asphalt ordinarily laid in the United States, but the speaker has no knowledge of any case in which this has been tried.

Mr. Lesley. R. W. LESLEY, Assoc. Am. Soc. C. E.—The figures in the paper as to the number of yards of asphalt in this country, some 27 500 000 sq. yds., represent, in cubic contents, only about one-third of the volume of concrete which underlies the asphalt, and the author has well said that the asphalt is the carpet on the floor of concrete. It has been found in all asphalt pavements that the concrete base is fully as important as the asphalt coat on top, for the carpet on the floor is of little importance unless the floor be solid.

In Buffalo, N. Y., where a large amount of these pavements has been laid, much of it was placed over concrete which subsequently expanded. The result was that the asphalt broke at the crown of the street, and the sections were forced to overlap. In Philadelphia, an asphalt pavement was once put down on a street soon after a sewer had been built through it. The sewer was on bad ground, and settled. Subsequent investigation showed that for some time the traffic on this part of the street, an important one, was carried entirely by the arch of 6 ins. of concrete and 2 ins. of asphalt.

Mr. Lesley.

The effect of freezing on concrete foundations of pavements was investigated carefully a number of years ago in connection with work done in Washington and Philadelphia. Pavements were put down in winter, and a short time afterwards were opened for some reason, when it was found that the concrete had not set, but simply frozen. The asphalt was replaced, and in the following fall, when it was removed for another examination of the concrete, it was found that the concrete had nearly as much strength as if it had set in the regular manner. The explanation is that the water in the concrete was frozen almost as soon as the material was placed, and was then sealed over with the layer of asphalt, preventing the access of air or moisture. When the mass was thawed out in the spring, the water was freed and entered into chemical action with the cement to form silicates and aluminates of lime as in the usual course of setting.

The oil in the Kentucky asphalt, to which reference has been made, is very light compared with that in the Trinidad and Bermudez asphalts, and requires admixture with heavier oils to make suitable paving material. As there is a large field of this asphalt along the Ohio River near Cloverport, it is interesting to learn from Mr. North that it can be used successfully in pavements when mixed with other ingredients.

Mr. Evans.

M. E. Evans, Jun. Am. Soc. C. E.—The unreliability of petrolene determinations by means of petroleum ether was very carefully investigated by E. G. Love, Ph. D., chemist for the Department of Public Works, New York City, with the result that he does not credit the values obtained by this method, and is working now along the lines followed by Dr. Endemann, as referred to in the paper.

Some authorities require a definite percentage of petrolene as essential to success with asphalt. The following approximate figures, determined by the customary method, would seem to indicate that considerable variation in this percentage has been found successful with different materials.

Assuming two representative American asphalts, Nos. 1 and 2, and one rock asphalt, No. 3, each one making a successful pavement, though varying considerably in the percentage of petrolene, and assuming the values of No. 1 as standard, the ratios of Nos. 2 and 3 relatively to No. 1 are as follows:

	No. 1.	No. 2.	No. 3.
Petrolene in bitumen........	100	77	133
" " mixture........	100	107	123

From this it seems that the rock asphalt has an excess of petrolene over Nos. 1 and 2, but it is apparently a drier mixture.

Foundations.—In New York most of the asphalt is laid on the regulated "present pavement." The old stone blocks are lifted, the subgrade regulated parallel to and 10 ins. below the finished surface of

Mr. Evans. the street, and the blocks are paved back again similar to a new stone pavement, the joints being filled with sand or gritty earth.

Upon this foundation, thoroughly swept and cleaned, the asphalt is laid in the usual manner. About two-thirds of the asphalt pavements are laid on this foundation.

It is common to find the street immediately preceding the construction of the pavement entirely torn up by gas and subway companies. If rain occurs during the progress of the work, or if the openings are not properly refilled, the blocks will be rendered very unstable.

Rolling this foundation pavement has been tried with indifferent success, the sub-grade being rolled if at all soft; but a method recently employed promises a better treatment of this class of foundation. The joints are well filled with sand or gritty earth and the street thrown open to traffic, toothing stones and headers being protected by earth-cushion and planking.

A few days of traffic and possibly a good rain serve to compact this foundation very thoroughly. The joints are then swept out sufficiently to afford an anchorage for the binder and the pavement laid as usual. In sweeping out the joints after traffic, considerable difficulty is experienced, as the filling compacts very solidly. The customary requirement of a 2-in. joint is found under such conditions to be impracticable, and a joint of a depth equal to its width is found to afford an ample anchorage, while it is possible to clean with a scratching tool and stiff broom. This joint will also be found to fill completely with binder, which is not true of a pavement paved before the filling has weathered.

A point of special weakness in this class of foundation is adjacent to the curb. On streets where light, single trucks line up along the curb (called for convenience "standing traffic"), the wheel, standing in the gutter, exerts a small but continued pressure, tending to force the binder and top downward between the curb and adjacent stone block where the jointing has seldom been very thoroughly done. A slight depression will cause water to lodge at this point and prove an active agent in the decay of the pavement. Some very good streets in this city have failed from this cause.

Of asphalt on concrete New York has about 23 miles, of which some is 12 ins.; generally, however, the thickness is 6 ins., though 5 ins. is now being used under some of the asphalt block pavements.

Of asphalt on macadam some 10 miles are now laid. The macadam surface is first picked up, swept and the surface regulated to the proper crown with broken stone, rolled, and slushed with tar, enough being used to render the mass rigid, but none in excess.

Compression.—Too much emphasis cannot be given to the value of thorough rolling and cross-rolling in the construction of good pave-

ments; and especially to the necessity for thorough tamping where the roller cannot go, as in the pockets of the track toothing stones. Many of the companies do not seem to have realized the value of this treatment until recently. Mr. Evans.

Successful work at this point has been accomplished by tamping the pockets in two layers. The force of the blow of the tamper is often expended on the stone, in fact generally so. A tamper should be specially devised for this work; one on the principle of the nail puller might be used; a tamping foot $3\frac{1}{2}$ ins. square, having a $\frac{3}{4}$-in. rod through its center, with a cylindrical weight or hammer $3\frac{1}{2}$ ins. in outside diameter and 8 ins. deep, with a $1\frac{1}{4}$-in. pipe through the center, sliding on the rod.

By placing the foot of the tamper in the pocket, the blow from the hammer can be directed accurately and made to give much greater force. If toothing stones are to be used, the pockets should receive the greatest possible attention. The great wear of these blocks is undoubtedly due to the initial jar from wheels bouncing from the long stones over the pocket where the asphalt has settled below the level of the blocks.

Defects in Pavements.—Some of the causes of defects in asphalt pavements are due to the following causes:

During Construction.

1. Overheating the asphaltic cement itself, or by mixing with overheated sand.
2. Failure in proportioning the dust to the sand, and the cement to both.
3. Laying too cold.
4. Laying on green concrete or a damp foundation.
5. Masses of tar in the binder course, which will soften the pavement under heat.
6. Lumps of rich material from the mixer blade, causing a lack of homogeneity in the surface.
7. Bad foundation.
8. Poor compression.

During Maintenance.

1. Standing traffic.
2. Imperfect drainage.

   A.—Causing water to stand in the gutters (this is sometimes accomplished by piling street sweepings against the curb).

   B.—Causing water, after cold rains, to stand in depressions or on flat places, where heavy traffic tends to cause scaling. New York City pavements suffered quite generally from this cause last winter.

Mr. Evans. The advantage of a three-center curve having its longer radii adjacent to the curb for the transverse section of the street finds support in the above. The scaling occurred generally on the crown of the street. That section which provides the sharpest curve at the crown reduces the opportunity for water to lodge at that point.

The rule for crowns in New York City being $\frac{1}{100}$ of the street for the crown and $\frac{1}{180}$ for the quarter, the elevation of the crown of a 30-ft. street will be $3\frac{1}{2}$ ins., and that of a quarter point $2\frac{1}{4}$ ins.

3. Street Openings.—From the report of the general inspector of street openings of New York for 1896, it seems that there were some 59 000 openings in the streets requiring repairs, a large percentage of which were on the asphalt streets.

4. Fire Burns.—During the year 1896, 8 654 sq. yds. of asphalt pavements were destroyed by fires and bonfires, costing the city over $30 000.* The area burned for the preceding years was as follows: 1894, 3 410 sq. yds.; 1895, 3 692 sq. yds.

5. Escaping Illuminating Gas.—Escaping gas carries a solvent to the asphalt which softens it. Heavy traffic tends to shear the pavement by rolling the soft asphalt under the tread of the wheel; the tensile strength being weakened, that part under the tread shears from the adjacent body and shows in irregular cracks, parallel to the traffic. When these cracks open, the water soon robs the surface of the crack of its cementing quality, and the pavement rapidly goes to pieces. The form of failure is that termed "macaroons" by M. Malo, a failure similar to that observed in rock asphalt streets laid on green concrete. Chemical analysis fails to prove the presence of gas or its ingredients, but it is easily detected by the odor.

6. Steam.—The steam-heating companies have mains which prove a menace. The heat and escaping steam softens the asphalt similarly to escaping gas.

7. Oil Dripping from Kerosene Wagons Softens the Asphalt.—In the tenement districts the oil men say that their customers will not take the oil unless the cans are filled until they begin to run over at the funnels.

8. Center-Bearing and Side-Bearing Rails and Toothing Stones.—The paper† by Edward P. North, M. Am. Soc. C. E., entitled "The Influence of Rails on Street Pavements," shows the kinds of rail in use in New York City. The recently introduced grooved girder rail, with the asphalt paved flush, is doing a great deal to mitigate the street rail nuisance.

The prime cause of wear in a street pavement is the first jar or jolt; a quiet rolling load does very little execution, but the same load received with a shock soon wears away the best pavement.

*Report of Water Purveyor of New York City for 1896.

†See *Transactions*, Vol. xxxvii, p. 70.

9. Stop-Cock Boxes of the Gas Companies and Manhole Heads of the Subway Companies.—The custom of having two or three companies' gas mains in the same block, while rendering practically impossible economic distribution of gas, causes generally a group of two or three stop-cock boxes in front of every building. The subway boxes, 32 ins. square, are put in about 100 ft. apart. Their form does not lend itself to easy crowning of the street, especially on intersections, and their long joints are necessarily parallel to the traffic. It is possible to set the stop-cock boxes at an angle with the traffic, but the subway boxes are too large. Many of the older forms of subway boxes were an iron frame on a creosoted wooden box. Mr. Evans.

Proportioning a Mixture.—The exact proportions of successful pavements have been determined after many years by the different asphalt companies in which their record of mixtures, chemical analyses, failures and successes of pavements have been studied and compared. In general, the principles governing the variation in proportions are as follows:

I.—A mass of sand having a small percentage of voids is produced by the use of a tempering sand or dust (powdered lime or quartz), or both. To this is added an asphaltic cement of sufficient fluidity to coat thoroughly and completely all the grains of the mineral mass in such quantity that (1) each grain will be coated with the thinnest possible coating; (2) having received its ultimate compression, the pavement will be free from voids; (3) so that this coating shall be of sufficient rigidity to prevent undue flowing, creeping or rutting in hot weather; (4) so that this coating shall be of such tenacity as to resist the tendency to scale in winter under heavy traffic after cold rains.

II.—The amount of asphaltic cement to be added to a certain mixture of sand depends on the following conditions: (1) to coat the grains; (2) to take up the dust; (3 to fill all the voids.

In determining the effect of reducing the average fineness of the sand, it is found that the surface varies inversely with the diameter approximately, or the decrease in the average size of the grains will require an increase in the quantity of cement to coat the increase in surface of grains. A sand high in dust will require a larger percentage of cement, since this material tends to stiffen the cement as flour stiffens batter.

A sand of uniform grains makes a pavement having a greater tendency to rut in warm weather than one where the grains are of graded sizes. The reason for this lies rather in the stability of a dry pile of the sand than its greater percentage of voids. When the grains mesh well with each other, they will present a greater number of bearing points against adjacent grains than when, being of the same size, the method of aggregation is uniform.

Mr. Evans. The following analysis of a pavement (No. 1), which proved very much too soft in summer, is compared with a sample from a successful pavement, No. 2, the mineral matter alone being considered:

	No. 1.	No. 2.
Mineral matter retained on No. 20 sieve........	1.1%	4.4%
" " No. 40 "	22.4%	19.2%
" " No. 60 "	51.5%	24.1%
" " No. 80 "	14.5%	21.0%
" " No. 100 "	0.7%	3.1%
Pass.....................No. 100 "	9.7%	28.2%

From this table it appears that No. 1 has more than 50% of its grains of one size, while No. 2 has not much more than 25 per cent. It is probable that No. 1 did not have limestone enough to render the sand coating rigid.

If, now, the grains are coated thinly with a cement which has been rendered stiff by the dust which fills the small interstices of the mineral mass, and the whole subjected to a rolling compression by which the coated grains are brought to a solid bearing, the resulting pavement will resist any tendency to displacement under heavy loading better than one with grains of uniform size, other conditions being properly provided for.

III.—Dust as a hardener. The most important function of the dust seems to be in its action as a hardener or stiffener.

Cement alone as a coating for grains of sand will permit them to be moved past each other freely under the influence of pressure and summer temperature. When cold this action is still possible, but in a smaller degree. The addition of an impalpable powder tends to reduce this action by rendering the coating more rigid, while not greatly increasing its thickness. This percentage of dust, if increased too high, will render the mass brittle in winter. The proper percentage lies as near as possible to this last stage without realizing its failings.

There is about 10% of the sand mass of successful pavements which is an impalpable powder capable of passing a No. 200 sieve.

Some sands are naturally high in clay or very fine silt, which reduces the percentage of fine dust, which must be added.

IV.—The difficulties in practical manipulation of the material in large quantities are many. Lime dust in the form of a powder is very liable to ball up in such a way that it becomes coated simply as a grain of sand rather than in the form of a powder uniformly disseminated through the sand ready to be taken up uniformly by the cement.

In drying and heating large quantities of sand, any loose handling of the material is liable to separate the coarse from the fine particles, causing a lack of uniformity in the grading of the sand in two batches of the same material.

An ordinary 2 000-yd. plant will have to melt and oil about 150 barrels of asphalt every day, heat uniformly and convey without separation of particles 110 cu. yds. of sand from the pile through sand drums, elevators, sand bins and boxes to the mixer, with 4 to 8 cu. yds. of impalpable powder uniformly mixed through the sand, each grain carefully coated with cement, the mixture to be conveyed to the street at the exact temperature required. Mr. Evans.

It is not uncommon in drawing sand from the bins into the box to draw it half full of sand at 400° to 500° Fahr., and top off with colder or cold sand from a pile on the platform. It would take some time in the mixer to bring this mass of hot and cold sand to a uniform temperature, yet the cement generally follows the sand almost instantly and before the dust which has been thrown into the box in bulk has had time to become mixed at all.

Not more than 1½ minutes or 100 to 120 revolutions of the mixer is allowed for the entire operation of bringing the sand to a uniform temperature, completely intermingling the dust with the sand and coating the particles with the cement.

Some Peculiarities of Good Pavements.—The following is abstracted from the annual report of Edward P. North, M. Am. Soc. C. E., water purveyor of New York City for 1896:

"During the hot weather of this summer complaints were made that many of our newer pavements were soft, and that with heavy loads the wheels sunk into them, increasing the necessary tractive power. The charge was true; though, except in the case of new pavements laid within a few weeks, this sinking of the wheels was very slight. In any pavement made from a compound of bitumen with sand, and a hardener, such as powdered limestone or granite, it is advisable that the mixture should remain soft for the first season, as otherwise it is liable to scale and flake off under heavy traffic when there is a cold rain. This trouble must be endured unless rock asphalt pavements are specified, and there has been some prejudice against them on account of their being rather more slippery than the compound pavements."

"The complaints against asphalt pavements are very general on the part of truckmen, but although they say a granite pavement is better, they will not follow a granite pavement when an asphalt pavement is available. * * * The loads hauled in this city are very heavy. A great many two-horse trucks are hauling loads of 5 tons or more, besides the weight of the truck, and many three-horse trucks carry loads of over 9 tons. None of these injure or deface a pavement that is more than one season old, and our heavy trucks carrying spools of cable for the traction companies have in no instance, that I can learn of, injured an asphalt pavement, although one load was decidedly over 20 tons to the wheel—that is, counting the weight of the spool and the truck; and other loads have been of between 17 and 20 tons per wheel. These loads, however, are destructive to cross-walks and injurious to granite pavements."

Maintenance of Asphalt.—The following further abstract from the report gives the status of maintenance contracts in New York City,

Mr. Evans. the custom being to let contracts for ten years' maintenance at a price per square yard per annum.

"During this year contracts have been entered into for maintenance of streets covered with asphalt, on which the guarantee has expired. The list of these contracts, * * * with the areas, the price paid per square yard for maintenance, and the date of expiration of contracts, is given below. Numbers one and two were let on the 24th of May, 1895, and the others have been let during this year. All these contracts are made for pavements which have been down five years or more."

	Area, square yards.	Price per square yard.	Expiration of maintenance.
No. 1	27 359	$0.3511	December 31st, 1905.
No. 2	31 702	0.3028	December 31st, 1905.
No. 3	24 061	0.12	August 25th, 1906.
No. 4	9 223	0.07	August 25th, 1906.
No. 5	4 330	0.065	August 31st, 1906.
No. 6	3 538	0.115	December 31st, 1906.
No. 7	11 697	0.08	December 24th, 1906.
No. 8	8 843	0.06	December 24th, 1906.
No. 9	6 515	0.07	December 24th, 1906.
No. 10	2 522	0.13	September 30th, 1906.
No. 11	11 038	0.12	September 30th, 1906.

"It will be noticed that the average cost per yard for maintenance per annum on all these maintenance contracts is slightly less than 19.9 cents. But if the maintenance of Eighth Avenue (No. 1), where the circumstances were exceptional, as the cost is over 30 cents per yard, and where the entire surface had to be renewed, be eliminated, the average cost will be found to be a fraction less than 9 cents per yard per annum for the ten years that the areas are under maintenance. If this price is applied to the contracts for this year, which were let at about $2.75 per square yard, the total cost of a pavement for twenty-five years, without the computation of interest, would be $3.65 per square yard, or 14.6 cents per annum. If interest at $3\frac{1}{2}\%$ is included on the various payments made and to be made, which are as follows: 70% on the completion of the work, and 3% per annum for ten years, commencing with the sixth year after the completion of the work, and semi-annual payments on the maintenance, the gross cost of the payment at the end of twenty-five years will amount to a fraction less than $7.74. This sum would be extinguished by annual payments of 19.9 cents, with $3\frac{1}{2}\%$ interest at the close of twenty-five years. So it may be stated that the present cost of our asphalt pavements is 20 cents per square yard per annum for twenty-five years."

"In England the average cost of asphalt pavements is $3.63 per square yard, and after the second year a payment of 25 cents per square yard for maintenance was made for fifteen years. This takes care of the pavement for seventeen years. If we treat this as above, we find the total cost at the end of seventeen years is $1.109. This sum would be extinguished by annual payments of 48.8 cents for seventeen years, with $3\frac{1}{2}\%$ interest, or decidedly more than twice the annual charge for our pavements for twenty-five years."

Asphalt Pavements Too Expensive for Heavy Traffic.—This claim does not conform entirely to experience in New York. Bids received by the Department of Public Works for paving First Avenue, the great trucking route of the east side to Harlem, showed that the average bid from five companies for asphalt on present pavement with fifteen years' guarantee was $3.054 per square yard, while the bids for granite on concrete to be maintained the same length of time averaged $3.50, a difference of 14.6% in favor of asphalt, with a higher standard of condition required at the expiration of the maintenance contract. Mr. Evans.

The mileage of pavements laid in New York City up to January 1st, 1897, on the basis of a 30-ft. street, was as follows: Total paved streets, 400 miles; total asphalt, 100 miles. The asphalt may be classified as follows: Total Trinidad Lake, 76 miles; total Trinidad land, 6 miles; total Alcatraz, 7 miles; total rock asphalt, 6 miles; total Bermudez, 2 miles; total asphalt block, 2 miles.

CORRESPONDENCE.

Marshall Morris, M. Am. Soc. C. E.—The writer has experimented for a number of years on mixtures of Kentucky rock with both European and American asphaltic limestones. About 10 miles of pavements of this nature have been laid in Buffalo, beginning in 1891. The proportions of the mixtures vary from 66⅔ to 90% of Kentucky rock, and 33⅓ to 10% of Vorwohle rock. Mr. Morris.

The Kentucky rock would undoubtedly be very serviceable in replacing the sand and a large part of the bitumen in the construction of pavements made with Trinidad or other asphaltic cements as the matrix, but commercially would hardly be a success, as the sand can be obtained at very low cost in most cities.

An analysis of the sand rock which is the basis of the Kentucky bituminous rock gave the following results, in percentages: Silica, 96.88; sesquioxide of iron, 0.81; alumina, 0.46; lime, 0.34; magnesia, 0.20; soda, 0.81; potash, 0.20; combined water and loss on ignition, 0.25.